A NEW 400-VOLT HORIZONTAL OUTPUT TRANSISTOR

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INTRODUCTION

The requirements of a TV horizontal-sweep circuit include generation of signals at a horizontal scan rate of 15.75 kilohertz, amplification of these signals, generation of a current sawtooth through a deflection yoke, and generation of the picture tube accelerating voltage of 10 to 20 kilovolts. A block diagram of the circuit to perform these functions is shown in Figure 1.

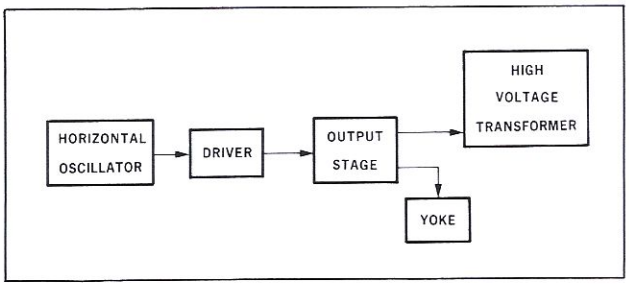

Fig. 1. Block Diagram.

Both the oscillator and driver functions are performed by low-power switching devices that are readily available. However, the stringent requirements on the output transistor have eliminated all but a few special types.

CIRCUIT REQUIREMENTS

To estimate the requirements of the output device, let us look at Figure 2, which shows the schematic of a basic current sweep circuit along with pertinent waveforms. As a starting point, consider the output stage is turned ON and the yoke current is zero. Current will increase linearly

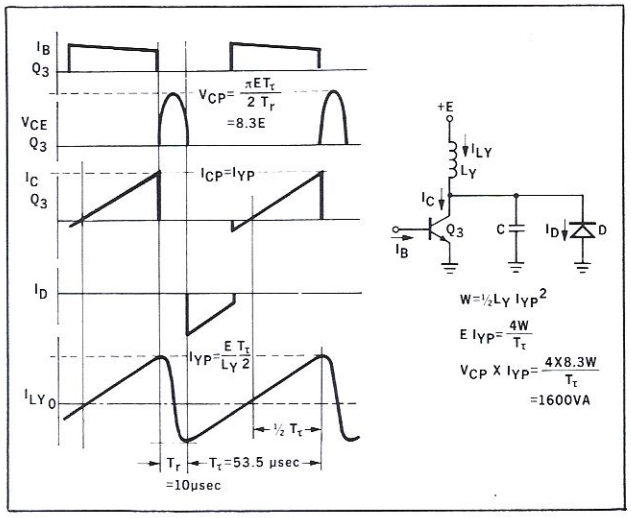

Fig. 2. Basic Current Sweep Current and Waveforms.

with time since the output transistor is in saturation and the load may be considered a pure inductor. At the end of the sweep, the output device is turned OFF and the collector current rapidly decreases to zero. The yoke current now flows into the retrace capacitor C, and the voltage across the capacitor and transistor increases sinusoidally. At maximum voltage, the yoke current is zero and becoming negative, then continues to flow in a negative direction until the transistor and capacitor voltage reaches zero and tries to go negative. At this point, the damper diode, D, conducts the full negative yoke current. The yoke current decreases in value and, at some point before it reaches zero, the output stage is again turned ON. At this time, the output transistor starts conducting the yoke current, and the cycle repeats.

*Consumer Applications and Transistor Engineering, respectively, Fairchild Camera and Instrument Corporation, Mountain View, California.

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Since, the transistor is operating as a switch, it is important to derive an expression for the maximum collector current required and the maximum collector-to-emitter voltage the device must withstand. These quantities may be obtained from a knowledge of the energy needed to deflect an electron beam in the TV picture tube. It is sufficient here to know that 2.5 millijoules of energy is required to deflect the beam of a typical 19-inch, 20-kV, 114-degree tube from center of screen to the edge.

The peak collector flyback voltage can be estimated from:

$$V_{c(peak)} = \frac{\pi E T_t}{2T_r} \quad (1)$$

where E = supply voltage

T_t = trace time (53 μs)

T_r = retrace time (10 μs),

thus solving

$$V_{c(peak)} = \frac{\pi \times 53 \times 10^{-6}}{2 \times 10 \times 10^{-6}} \times E = 8.3\ E\ . \quad (2)$$

It will be noted that the flyback voltage is dependent only on the power supply voltage, trace and retrace times, and has nothing to do with the energy requirements of the sweep system.

The current required in the yoke is dependent on supply voltage. By noting that:

$$E = L_y \frac{di}{dt} \quad (3)$$

and integrating,

$$I_{y(peak)} = \frac{E}{L_y} \frac{T_t}{2}\ . \quad (4)$$

Also, $$W = \frac{1}{2} L_y \left(I_{y(peak)}\right)^2\ . \quad (5)$$

Eliminating L_y,

$$E I_{y(peak)} = \frac{4W}{T_t}\ , \quad (6)$$

where

L_y = yoke inductance

T_t = time during trace, 53×10^{-6} seconds

$I_{y(peak)}$ = peak yoke current

W = energy needed to deflect beam from center to edge of tube. From Equation (2), the required volt-ampere product for the output device is:

$$V_{c(peak)} \times I_{y(peak)} = \frac{4 \times 8.3\ W}{T_t} \quad (7)$$

or $$V_{c(peak)} \times I_{y(peak)} = 1600 \text{ volt-amperes.} \quad (8)$$

This figure considers the requirements of the output transistor driving only the deflection yoke. However, it is necessary to add the high-voltage transformer and provide a safety margin on the device voltage rating to build a practical circuit.

Figure 3 shows a typical circuit of an output stage with the high-voltage transformer. The yoke has been ac-coupled to ground to prevent a dc component from flowing through it. The primary of the output transformer is now used as the collector load.

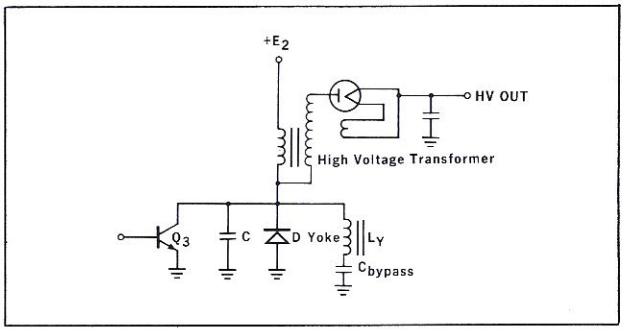

Fig. 3. Typical Horizontal Output Circuit.

The volt-ampere requirements of this circuit can be estimated by adding a safety factor of 35 percent to both the peak current and voltage seen by the output transistor:

$$V_{c(peak)} \times I_{c(peak)} = 1600 + 0.35\ (1600) + 0.35\ (1600)$$

$$= 2800 \text{ volt-amperes.}$$

In addition to this parameter, it is necessary to provide good transistor saturation characteristics at the required collector current. The device should have high gain to minimize the requirements of the driver stage. The transistor turn-off time should be made as short as possible for efficient device and circuit operation. If the turn-off time is too slow, greatly increased switching losses will be added to the device dissipation and circuit efficiency problems, and possible device failure will result.

The following is a summary of the horizontal output transistor requirement.

1. Peak voltage-current product greater than 2800 volt-amperes
2. Low collector saturation at peak collector current
3. High dc current gain at peak collector current
4. Fast, turn-off fall time.

OUTPUT TRANSISTOR DESIGN

The SE9020 was designed to meet the above stated requirements. Breakdown voltage and collector current are the two uncompromising requirements of this application. A collector-to-emitter breakdown voltage of 400 volts and a collector current of 7 amperes was selected as the most economically and technologically feasible combination.

Until recently, 400-volt Planar* transistors were not readily available. The development of the equipotential

*Planar is a Fairchild-patented process.

ring structure enables a marriage of the Planar process advantages and cleave-junction, high breakdown voltage capabilities. Figure 4 is a photomicrogram of the SE9020

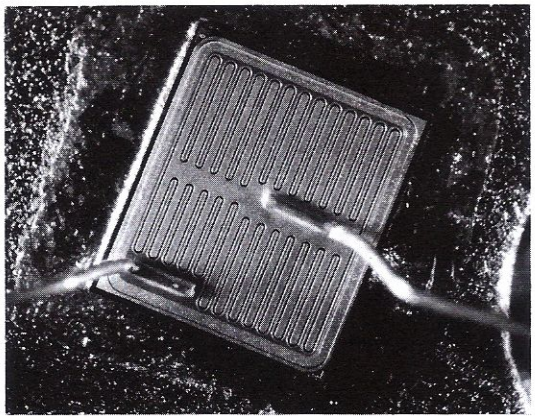

Fig. 4. Photomicrograph of the SE9020.

structure. Note the base metalization over the oxide-covered, high-voltage, collector-base junction and the additional outer metalized ring, which is electrically connected to the collector region at two diagonal corners of the structure. For this discussion it will suffice to say that the base over-metalization increases the collector-base junction breakdown voltage by increasing the effective radius of the junction corner and forcing the breakdown to occur in the semiconductor bulk rather than at the surface, while the outer ring prevents the potential channelling hazards of the inner ring.

The larger inter-digitated epitaxial structure provides high collector-current capability as well as high current gain, fast switching time, and low saturation voltage.

The SE9020 device characteristics are listed in Table 1.

A plot of dc current gain versus collector current (Figure 5) indicates that the gain at the 7-amp operating

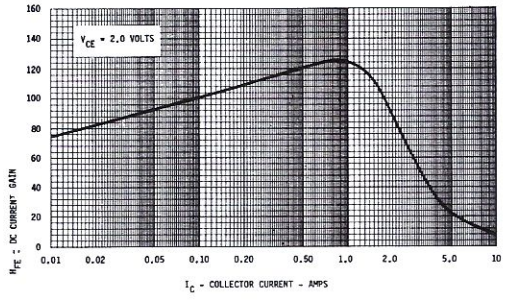

Fig. 5. Typical DC Current Gain versus Collector Current.

level is still sufficiently high to assure low base drive requirements. Figure 6 is a distribution plot of 7-amp current gain taken on fifty production devices. Results show a minimum gain of 10.7 and a maximum of 26.

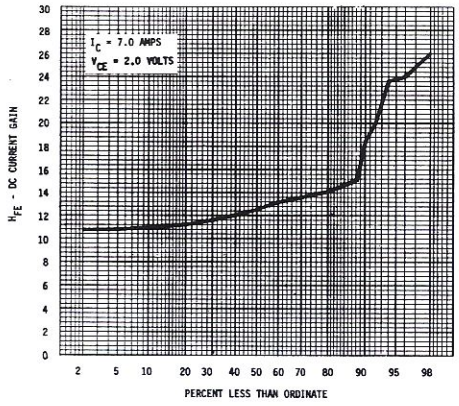

Fig. 6. DC Current Gain Distribution.

The low collector saturation voltage at 7 amperes is illustrated in the distribution plot of Figure 7 (taken with

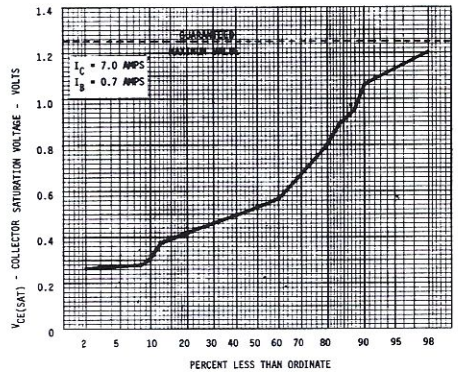

Fig. 7. Collector Saturation Voltage Distribution.

a base drive of 0.7 ampere). Note that the maximum guaranteed value is 1.25 volts.

Although the horizontal output transistor in the deflection circuit has no well-defined turn-off, fall time requirement, a value of 2 microseconds has often been used, and 1 microsecond has always been considered a desirable maximum value.

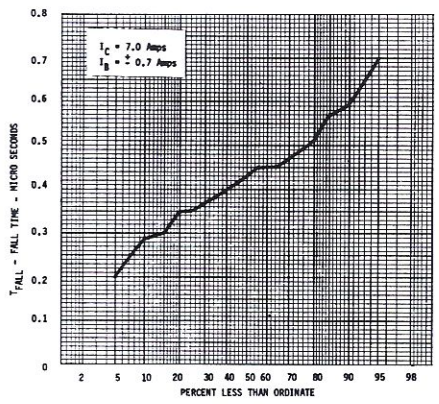

Fig. 8. Turn-Off Time Distribution.

Again, resorting to the distribution plot in Figure 8, we see that the guaranteed value of 1 microsecond is well above the typical and even the 90 percent point.

A TYPICAL HORIZONTAL DEFLECTION SYSTEM

A complete horizontal deflection system for a 19-inch, 110-degree 20-kV picture tube is shown in Figures 9 and 10.

The blocking oscillator (Figure 9) is used to generate the

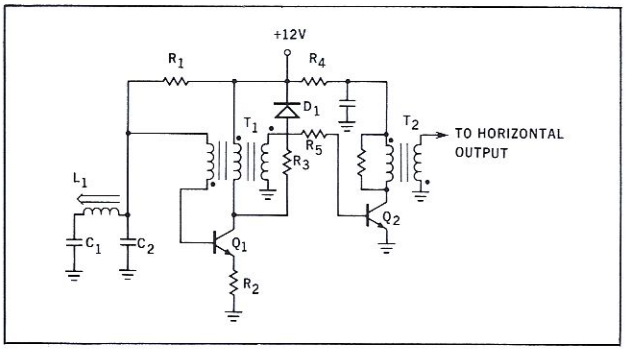

Fig. 9. Horizontal Oscillator and Driver.

horizontal operating frequency. This is a conventional blocking oscillator designed to produce a square wave of current drive to the base of the driver stage. The phasing of the transformer, T_1, is such that when the oscillator transistor is ON, the driver is driven ON. An L-C circuit is included in the base for stabilization of operating frequency and a diode-resistor network is used to limit the amplitude of the collector backswing.

The driver transistor, Q_2, is used to store energy in the driver transformer, T_2, and to drive the output stage, Q_3, into cut-off during retrace. Thus, Q_2 is driven ON and the output stage is driven OFF by the blocking oscillator. This results in efficient operation, since the driver can store energy in T_2 during retrace, and this energy can be used to hold the output stage ON during trace time instead of being wasted in a damping resistor.

The output circuit in Figure 10 is a slight modification of

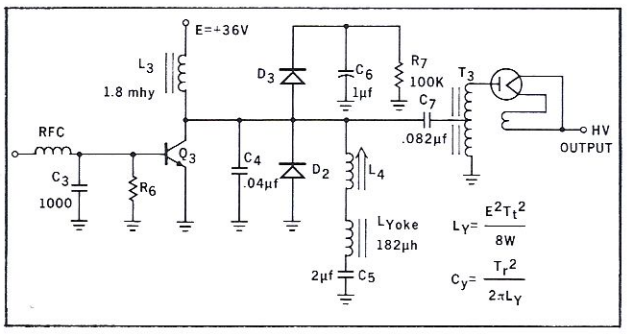

Fig. 10. Choke Coupled Horizontal Deflection Circuit.

the circuit shown in Figure 3. This circuit, known as a choke-coupled circuit, is chosen for its ability to protect the output device during high-voltage arcing conditions.

A typical 20-kV, 114-degree, deflection-angle sweep system will circulate 2.5 millijoules of deflection energy. From this, the value of the yoke inductance can be calculated:

$$L = \frac{E^2 T_t^2}{8W} \quad . \tag{9}$$

Solving for a 36-volt dc power-supply voltage,

$$L_y = \frac{(36\,V)^2\ (53 \times 10^{-6}\ sec)^2}{8 \times 2.5 \times 10^{-3}\ mJ}$$

$$= 0.182\ mH$$

$$= 182\ \mu H \ .$$

The peak-to-peak yoke current will be

$$di = \frac{Edt}{L_y} \tag{10}$$

or

$$I_{y(peak\text{-}to\text{-}peak)} = \frac{E\,T_t}{L} \tag{11}$$

$$= \frac{(36\,V)\ (53 \times 10^{-6})}{182 \times 10^{-6}}$$

$$= 10.5\ amperes \ .$$

In addition, current must be available to supply such requirements as the output transformer, choke, power losses in the circuit, and high-voltage loading. Of these components, only the reactive ones (choke and transformer inductance) will increase the peak-to-peak circulating current that both the transistor and damper diode must conduct. The choke, L_3, inductance is 1.8 millihenries, and the transformer, T_3, primary is approximately 1.5 millihenries. In parallel, these components represent 0.82 millihenries. The peak-to-peak current through these elements is:

$$I_{(peak\text{-}to\text{-}peak)} = \frac{(36\,V)\ (53 \times 10^{-6}\ sec)}{0.82 \times 10^{-3}\,H}$$

$$= 2.33\ amperes \ .$$

The total peak-to-peak sweep current requirement is 12.83 amperes. The peak end of sweep collector current equals the peak damper diode beginning of sweep current and is one-half the total sweep current, or 6.4 amperes (peak).

The remaining circuit losses, high-voltage loading, etc., will consume approximately 25 watts or 0.7 ampere. This is the current drawn from the power supply and adds just to the peak transistor current, giving a total of

$$I_{c(peak)} = 7.1\ amperes \ .$$

The retrace capacitor, C_4, is chosen to resonate with the circuit inductance during retrace at 50 kilohertz, giving a half-cycle retrace time of 10 microseconds. Its value can be found from

$$C_4 = \frac{Tr^2}{2\pi L} , \qquad (12)$$

where L = parallel combination of yoke, choke and transformer inductance, (0.15 mH)

$$= \frac{(10 \times 10^{-6}\ \text{sec})^2}{2\pi\ (0.15\ \text{mH})}$$

= 0.056 microfarads.

This value is not exact and will vary with transformer tuning and selection of the transformer coupling capacitor, C_7.

The collector flyback voltage, from Equation (1) is:

$$V_{c(peak)} = \frac{\pi \times 36\ V \times 53\ \mu s}{2 \times 10\ \mu s} = 300 \text{ volts}.$$

The flyback voltage is reduced approximately 15 percent by the action of "third harmonic" tuning of the high-voltage transformer. A transformer designed for third-harmonic tuning is wound in such a way that its leakage inductance resonates with its secondary distributed capacitance and the retrace capacitor to form a tuned circuit resonant at approximately three times the frequency of retrace, or 150 kilohertz. Actually, a value of 2.7 to 2.8 times the retrace frequency is optimum. The actual transformer is best designed by a trial-and-error process.

Protection against high-voltage arcing has always been a problem with transistorized deflection circuits. Unlike tubes, transistors will not stand high energy or voltage surges. There are three types of arcs that can and do occur in the high voltage section: (1) transformer arc: arcing from the voltage rectifier plate to ground; (2) CRT arc: arcing from the picture-tube anode to ground, across C_8; (3) rectifier arc: arcing across the high-voltage rectifier. Of these, the most serious appears to be the rectifier arc due to the high energy stored in the filter capacitor. Approximately 100 millijoules of energy is stored in the filter capacitor which, during a rectifier arc, is essentially short-circuited into the flyback transformer.

During these arcing conditions, the transistor is subjected to extreme current and voltage stresses. In the standard shunt-fed circuit, where the flyback transformer primary is in the dc path to the supply voltage, high-voltage arcing will make the primary inductance decrease greatly, thus causing the output transistor collector current to increase sharply. The output transistor's gain at high current will determine the load line shape. For transistors with good beta characteristics, the collector current will increase to a high value. Poor beta devices will come out of saturation and a high voltage-current condition will exist. Both the high and low beta devices will be subject to failure; the former due to high current overloads and the latter to high power dissipation for relatively long time durations. In addition, detuning of the transformer will alter the retrace ring frequency which determines the amplitude of the flyback pulse. The effect of detuning the transformer inductance is to increase the flyback voltage beyond safe limits for the output transistor.

Arcing will also generate electrical noise in various circuits of the TV receiver. If uncontrolled, this noise can forward-bias the output stage during retrace, when the collector-to-emitter voltage is high, and cause device failure.

The basic philosophy of the choke-coupled circuit is to isolate the flyback or high-voltage transformer from the output transistor. Tests have shown that adverse conditions due to arcing will last for several milliseconds. Since, under normal operating conditions, the output transformer must handle voltage pulses of 10-μs duration, it is possible to connect the output transformer to the output stage with a relatively small capacitor, C, realize good performance under normal operating conditions, and provide isolation for long-term arcing transients.

The choke, L_3, used as a load impedance must not saturate magnetically during conditions of arcing. This can be done by using a ferrite core structure with a large air gap. A ferrite rod serves well for the purpose. On a per-cycle basis, this choke effectively limits output collector current to a safe value, typically 1.5 times normal current, under arcing conditions.

The value of this choke does not appear critical, but should be 10 times the yoke inductance so that excessive loading does not occur.

Diode D_3 and the resistor capacitor combination of R_7 and C_6 are used to clamp the flyback voltage to a safe value during arcing. The changing time of C_6 should be longer than the disturbance times due to arcing.

RFC, C_3, and R_6 act as a low pass filter in the base of the output to prevent arcing noise from turning ON the output stage during retrace.

C_7, the high voltage transformer coupling capacitor was chosen experimentally from the data of Figure 11. This

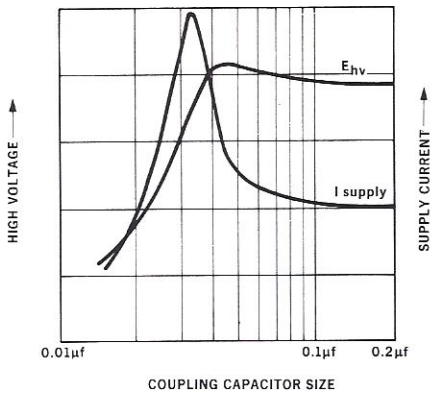

Fig. 11. Circuit Performance.

data shows how the current drawn by the output stage from the power supply and high voltage output vary as the size of C_7 is changed. It is desirable to choose this capacitor as small as possible while avoiding the resonant condition shown.

CONCLUSION

The good switching characteristics of the SE9020 make it a desirable device for the horizontal output stage of a TV receiver. Other uses for this transistor would include dc-to-dc converters, switching regulators, and similar applications.

TABLE 1

SE9020 Characteristics.

Collector to Emitter Breakdown Voltage (shorted base)	400 V (minimum)
Collector Saturation Voltage at I_c = 7A, β = 10	0.60 V (typical)
Base Saturation Voltage at I_c = 7 A, β = 10	1.20 V (typical)
Turn-Off, Fall Time at I_c = 7 A, I_B = ±0.7 A	400 ns (typical)
DC Current Gain at I_c = 7 A, V_{CE} = 2 V	10 (minimum)